NextNext Generation Reference Dwellings for Ireland: A Short Communication

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Recommended Citation: Li, C; Raushan, K; Essien-Thompson, E; Mulville, M; Ahern, C. 2025. "*Next Generation Reference Dwellings for Ireland: A Short Communication*", Irish Building Stock Observatory, Dublin, Ireland.

Executive Summary

This short communication presents a validated set of Reference Dwellings (RDs) suitable for use as inputs to a national-scale bottom-up engineering Dwelling Stock Energy Model (DSEM). This research builds upon research by the Irish Building Stock Observatory (IBSO) that characterised 52 RDs for Ireland using Machine Learning (ML) applied to the Energy Performance Certificate (EPC) database in 2024. This study analysed and hence selected 20 predominant RDs (from a set of 52) to represent 85% of the Irish housing stock for development, characterisation and validation.

Development, Characterisation and Validation

As shown in Table 1 to 19, three-dimensional (3D) geometric models of the 20 RDs were developed, incorporating building form, construction period, architectural style and living area percentage estimation. The 3D geometries characterised in this research were first validated using Real Example (ReEx) Buildings characterised by typology and construction period and sourced for each RD from various historical and contemporary references, including Irish Cities' history books [1], counties development plans [2], architectural archives [3], properties news, live maps [4, 5] and properties sale website [6-10]. The RD characterisations were enriched with key thermal and building envelope parameters, including air permeability, thermal bridging coefficients, and likely construction characteristics. This data enrichment enabled a secondary cross-validation process with EPC ratings and retrofit status classifications, validating alignment between the 20 RDs and Ireland's national housing stock characteristics.

Results and Recommendations

The validated RDs characterised in this research are robust and contemporaneous and are suitable for use as inputs to a national bottom-up engineering DSEM and should be used in place of outmoded historical RD characterisations such as TABULA [11].

Limitations and Future Research

In bottom-up energy stock modelling, the use of RDs serves as a computationally efficient approach to representing the diversity of the built environment. In this case, 52 RDs were initially identified by machine learning to account for 100% of the building stock, ensuring heterogeneity is captured. However, further analysis revealed that the top 20 RDs account for 85% of the stock, while the remaining 32 RDs collectively represent only 15%, with each of these less frequent RDs contributing less than 1.5% individually and 0.5% on average. Excluding 15% (32) of the less common dwelling RDs, highly distributed across a wide range of RDs, reduces the computational

burden. However, the selected RDs (20 RDs or 85% of built stock) remains highly representative of the national stock, balancing efficiency and accuracy. Given the objective of maintaining a manageable yet representative model, a strategic decision was made to prioritise the characterisation of the top 20 RDs. This approach is grounded in several key considerations:

1. Coverage Efficiency: The top 20 RDs capture the vast majority (85%) of the total dwelling stock, ensuring that the model remains broadly representative of real-world conditions.
2. Computational Efficiency: By focusing on the most numerate RDs, the model achieves a significant reduction in computational requirements, making large-scale simulations feasible without sacrificing meaningful insights.
3. Diminishing Returns on Inclusion: The remaining 32 RDs, while collectively accounting for 15% of the stock, each contribute less than 1.5% individually. Including them would significantly increase computational burden without proportionally enhancing the macro-level insights.
4. Robust Characterisation: The top 20 RDs inherently capture the predominant stock characteristics, providing a solid foundation for robust national-level energy modelling and data-driven policy insight.

Further limitations of this research include:

- The EPC dataset required extensive cleaning to validate the dataset to Eurostat level 3. 36% of the dataset was found to be 'bad data' and was removed from the dataset. Notwithstanding, data validation ensured that the remaining data was robust and suitable for RD characterisation.
- Air permeability values within the national EPC dataset were found to be misrepresentative this is because dwellings which had an air permeability test carried out, typically had other measures installed that reduced the calculated overall energy consumption to below average. This indicates that end-users motivated to test for air tightness already had air-tight low-energy dwellings. Hence air permeability data was sourced from a field dataset collated by an air tightness company in Ireland. Greenbuild Energy Rating and Building Information Services Ltd. have been conducting air-tightness tests in Ireland since mid-2007, amassing air-tightness test data relating to 187 refurbished as well as as-built Irish dwellings [12]. Empirical test data was averaged by typology and construction period and hence applied to RDs characterised in this work. While derived from a relatively small dataset, this approach provides an empirical basis for airtightness estimation. Future research could refine these assignments with broader empirical data.
- In the absence of the publication of thermal bridging coefficients (ψ-values) for Ireland, ψ-values were determined using the UK SAP guidelines. While this provides a structured and validated approach, future studies could refine these assignments with Irish-specific data.

Conclusion

This research validates and enriches the statistical ML-based approach to RD characterisation, characterising 20 predominant RDs suitable for dynamic modelling and national-scale DSEM inputs. These RDs are more representative, empirically validated, and data-driven alternative of Ireland's housing stock to those developed under existing frameworks, providing a scalable and adaptable foundation for energy performance analysis and evidence-based policy development.

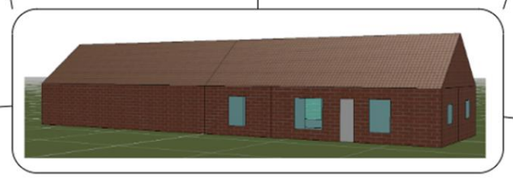
Typology No. 1 - Semi-Detached House (SD1)


1980s


1970s


1960s

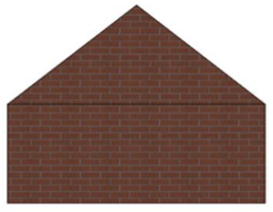
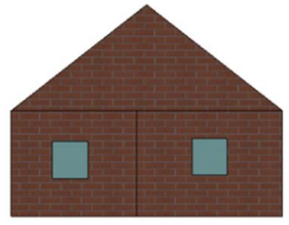

1990s


3D Reference Dwelling


1950s

Typology Details	
Typology	Semi-Detached House (SD1)
Construction Period	Avg. 1972 (Year Range: 1956-1995)
Floor Area (m^2)	80.02
Living Area (%)	20.5%
Representativeness (%)	11.30%
Architectural Style	Single Storey, Sloped Roof, Central Doors
Building Energy Rating Reference	F
Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

Thermal Characteristics			
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)
External Wall	300mm Cavity (Uninsulated) mostly rendered with cement/sand or exposed brick and internally light plastered.	1.54	70.30
Roof	>100 mm mineral wool Insulation between ceiling joists, roof space, tiling.	0.71	80.02
Ground Floor	Solid ground floor, uninsulated	0.56	80.02
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.90	13.30
Doors	Solid external door	2.68	2.98
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)			
10.0			
Thermal Bridging Coefficient (W/m^2K)			
0.10			

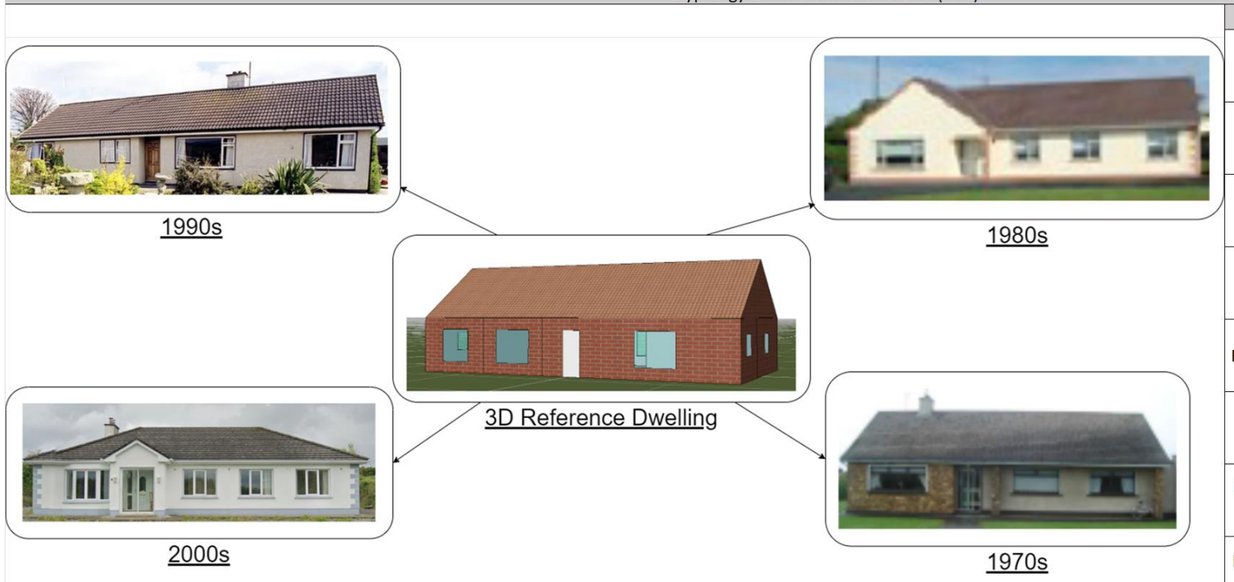
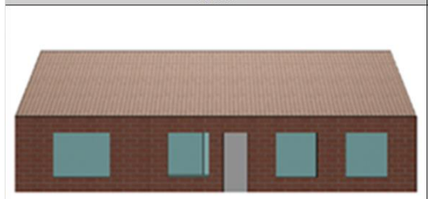
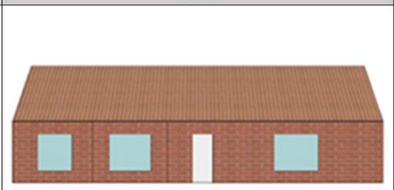
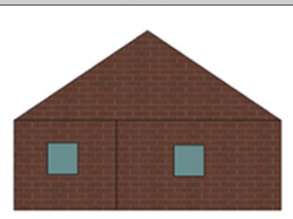
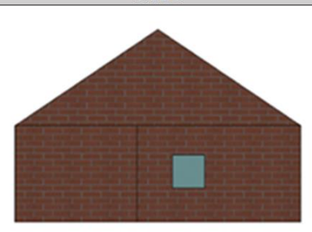
Building Service System Characteristics	
Space Heating Efficiency	78.54%
Domestic Hot Water Efficiency	78.53%
Predominant Primary Heating Source and Generator Type	Traditional centralised oil boiler to serve the space heating and domestic hot water

Reference Dwelling Description

Rural/suburban traditional bungalow, uninsulated concrete or cavity wall mostly rendered with cement/sand or exposed brick and internally light plastered, sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid door. Retrofit required.

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

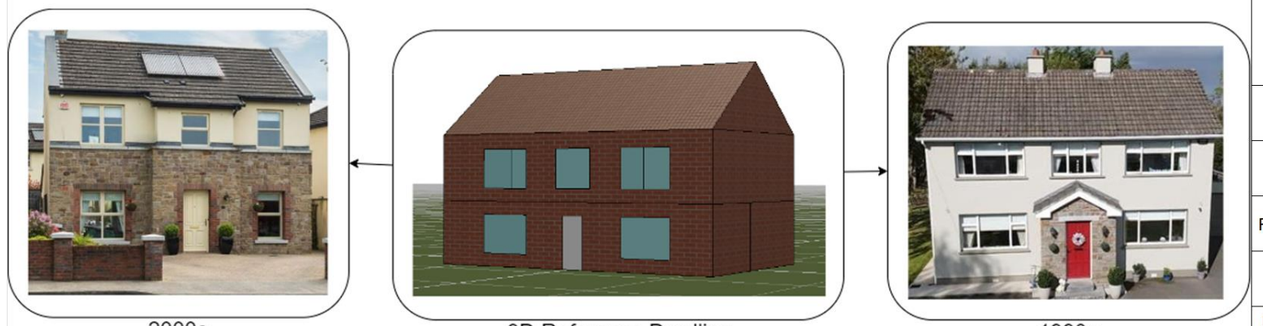
Table 1 Typology No.1 - 1956 to 1995 Semi Detached Bungalow with Oil Boiler

Typology No. 2 - Detached House (DE1)					
				Typology Details	
				Typology	Detached House (DE1)
				Construction Period	Avg. 1982 (Year Range: 1977-1996)
				Floor Area (m^2)	112.93
				Living Area (%)	18.5%
				Representativeness (%)	9.50%
				Architectural Style	Single Storey, Sloped Roof, Central Doors
				Building Energy Rating Reference	E1
				Requiring Retrofit/New Build	Requiring Retrofit
Elevation Images of Reference Dwelling					
Front	Back	Side 1	Side 2		
					
Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	79.91%
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.54	98.13	Domestic Hot Water Efficiency	79.93%
Roof	>100 mm mineral wool Insulation between ceiling joists, roof space, tiling.	0.43	112.93	Predominant Primary Heating Source and Generator Type	Traditional centralised oil boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, uninsulated	0.55	112.93	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.78	21.17	Rural traditional bungalow, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid door. Retrofit required.	
Doors	Solid external door	2.92	3.44		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
10.0					
Thermal Bridging Coefficient (W/m^2K)					
0.09					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

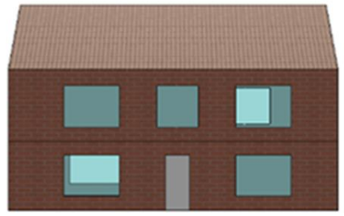
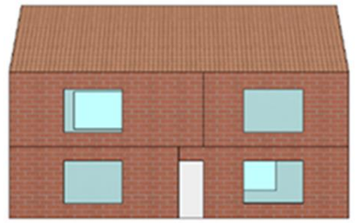
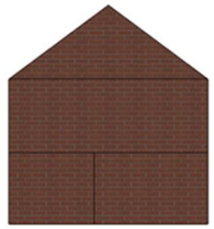
Table 2 Typology No.2 - 1977 to 1996 Detached Bungalow with Oil Boiler

Typology No. 3 - Detached House (DE2)



Typology Details	
Typology	Detached House (DE2)
Construction Period	Avg. 1995 (Year Range: 1995-2004)
Floor Area (m^2)	150.74
Living Area (%)	15.8%
Representativeness (%)	8.20%
Architectural Style	Two Storey, Sloped Roof, Central Doors
Building Energy Rating Reference	C1
Requiring Retrofit/New Build	Requiring Retrofit

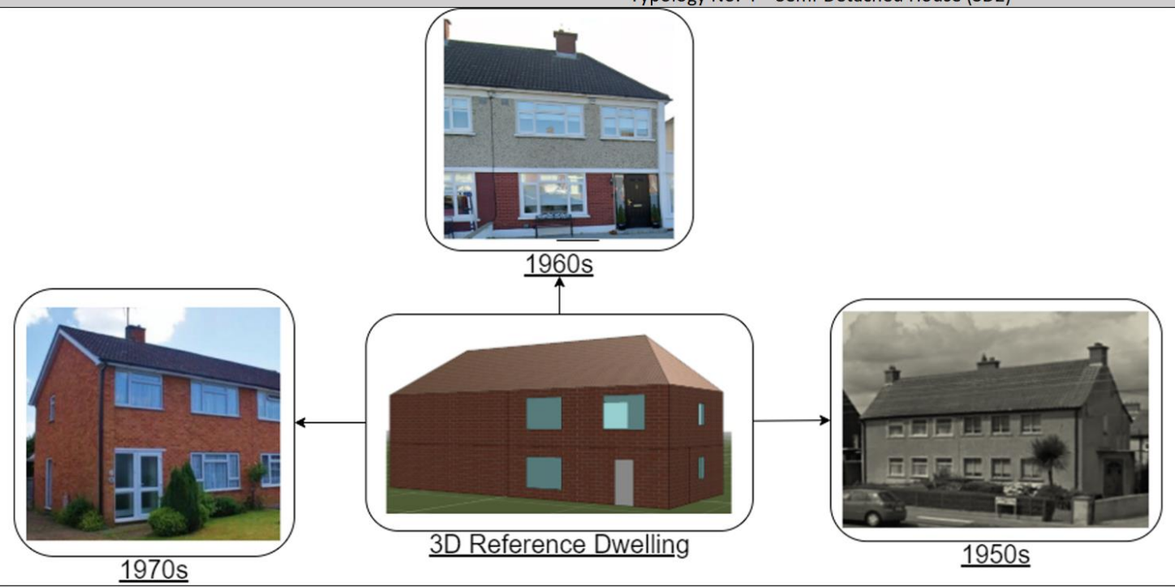
Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

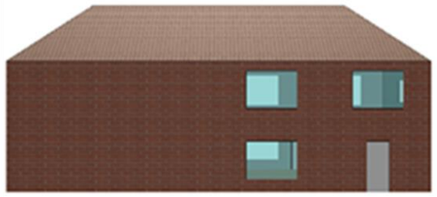
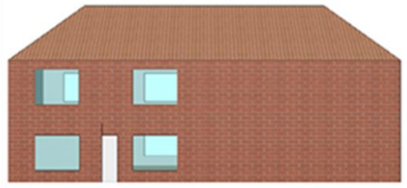
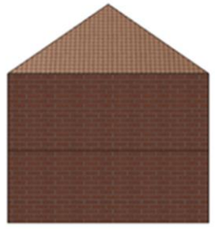
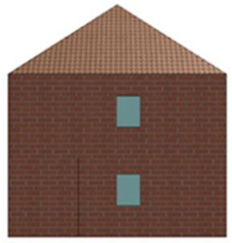
Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	83.84%
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.39	154.15	Domestic Hot Water Efficiency	83.91%
Roof	100 mm mineral wool Insulation between ceiling joists and 50 mm of mineral wood quilt over joists, roof space, tiling.	0.28	83.64	Predominant Primary Heating Source and Generator Type	Modern centralised oil boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, uninsulated	0.46	83.64	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.56	26.28	Rural/suburban modern detached house, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid door. Retrofit required.	
Doors	Solid external door	2.86	3.58		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
9.6					
Thermal Bridging Coefficient (W/m^2K)					
0.09					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 3 Typology No.3 - 1995 to 2004 Detached House with Oil Boiler

Typology No. 4 – Semi-Detached House (SD2)	
	

Typology Details	
Typology	Semi-Detached House (SD2)
Construction Period	Avg. 1959 (Year Range: 1950-1972)
Floor Area (m^2)	106.32
Living Area (%)	17.9%
Representativeness (%)	7.30%
Architectural Style	Two Storey, Sloped Roof
Building Energy Rating Reference	E1
Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling			
Front	Back	Side 1	Side 2
			

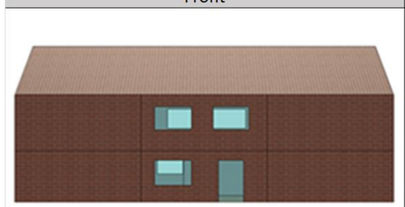
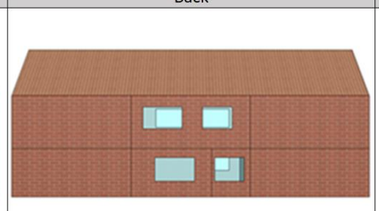
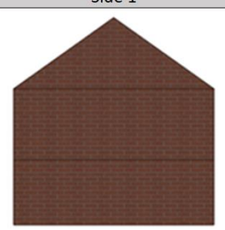
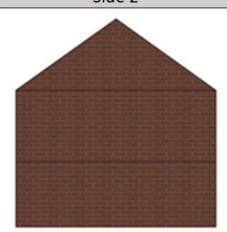
Thermal Characteristics			
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)
External Wall	Concrete Hollow Block (dry-lined)	1.20	94.52
Roof	50 mm mineral wool Insulation between ceiling joists, roof space, tiling.	0.71	58.71
Ground Floor	Solid ground floor, uninsulated	0.69	58.71
Windows	Double glazed windows, uncoated, PVC/Wood frame	3.26	20.41
Doors	Solid external door	2.85	3.10
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)			
10.0			
Thermal Bridging Coefficient (W/m^2K)			
0.12			

Building Service System Characteristics	
Space Heating Efficiency	80.61%
Domestic Hot Water Efficiency	80.66%
Predominant Primary Heating Source and Generator Type	Tradtional centralised natural gas boiler to serve the space heating and domestic hot water
Reference Dwelling Description	
Suburban/urban traditional semi-detached house, typically in traditional housing schemes/developments, concrete external wall (dry-lined) and sloped roof without insulation or with insulation at ceiling level (typically mineral wool), double-glazed windows and solid door. Retrofit required.	

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 4 Typology No.4 - 1950 to 1972 Semi-Detached House with Gas Boiler

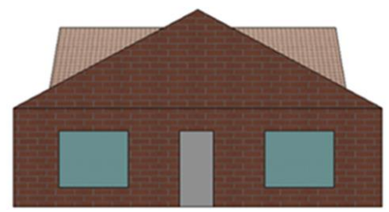
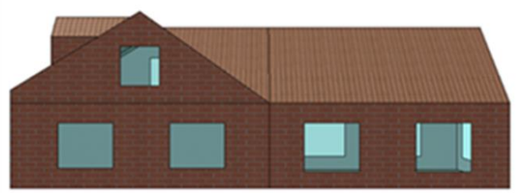
Typology No. 5 – Mid-Terrace House (MT1)					
				Typology Details	
				Typology	Mid-Terrace House (MT1)
				Construction Period	Avg. 1989 (Year Range: 1966-1982)
				Floor Area (m^2)	85.43
				Living Area (%)	20.3%
				Representativeness (%)	6.40%
				Architectural Style	Two Storey, Sloped Roof, Full/Partially Glazed Doors
				Building Energy Rating Reference	E1
				Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling			
Front	Back	Side 1	Side 2
			

Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	80.62%
External Wall	300mm Cavity (Uninsulated) mostly rendered with cement/sand or exposed brick and internally light plastered.	1.54	49.52	Domestic Hot Water Efficiency	80.65%
Roof	100 mm mineral wool Insulation between ceiling joists, roof space, tiling.	0.71	44.63	Predominant Primary Heating Source and Generator Type	Tradtional centralised natural gas boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, uninsulated	0.52	44.63	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	3.11	16.45	Suburban/urban traditional terrace house, typically in traditional housing schemes/developments, uninsulated concrete or cavity wall mostly rendered with cement/sand or exposed brick and internally light plastered, sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and glazed front door with entrance lobby, or a partially glazed front door (glazing area >50%). Retrofit required.	
Doors		-	-		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
10.5					
Thermal Bridging Coefficient (W/m^2K)					
0.16					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 5 Typology No.5 - 1966 to 1982 Mid-Terrace House with Gas Boiler

Typology No. 6 – Detached House (DE3)					
 2000s  3D Reference Dwelling  1990s				Typology Details	
				Typology	Detached House (DE3)
				Construction Period	Avg. 1992 (Year Range: 1991-2004)
				Floor Area (m^2)	230.77
				Living Area (%)	13.5%
				Representativeness (%)	5.60%
				Architectural Style	Two Storey with Dormer Windows, Extension, Sloped Roof, Central Doors
				Building Energy Rating Reference	C2
				Requiring Retrofit/New Build	Requiring Retrofit
Elevation Images of Reference Dwelling					
Front		Back		Side 1	Side 2
					
Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	84.43%
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.54	177.32	Domestic Hot Water Efficiency	84.41%
Roof	100 mm mineral wool Insulation between ceiling joists and 50 mm of mineral wood quilt over joists, roof space, tiling.	0.43	168.93	Predominant Primary Heating Source and Generator Type	Modern centralised oil boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, uninsulated	0.43	152.18	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.57	41.27	Rural/suburban modern detached house with dormer windows and back extension, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid external doors. Retrofit required.	
Doors	Solid external door	2.87	3.81		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
7.4					
Thermal Bridging Coefficient (W/m^2K)					
0.08					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 6 Typology No.6 - 1991 to 2004 Detached House with Oil Boiler

Typology No. 7 – Detached House (DE4_1)


1950s


1940s


1920s-1930s

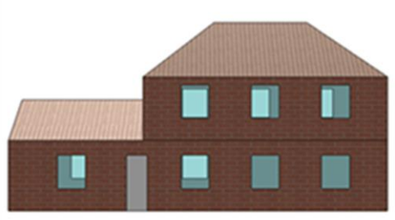
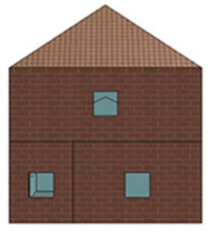

1960s-1970s


3D Reference Dwelling


1900s-1910s

Typology Details	
Typology	Detached House (DE4_1)
Construction Period	Avg. 1923 (Year Range: 1860-1976)
Floor Area (m^2)	133.27
Living Area (%)	17.1%
Representativeness (%)	4.10%
Architectural Style	Two Storey, Extension, Sloped Roof, Central Doors
Building Energy Rating Reference	E2
Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

Thermal Characteristics			
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)
External Wall	225mm Solid Brick rendered externally and with 13mm lime plaster internally.	1.55	145.74
Roof	<50 mm mineral wool Insulation between ceiling joists, roof space, tiling.	0.71	81.21
Ground Floor	Solid ground floor, uninsulated	0.80	81.21
Windows	Double glazed windows, uncoated, PVC/Wood frame	3.38	20.72
Doors	Solid external door	2.88	3.35
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)			
11.0			
Thermal Bridging Coefficient (W/m^2K)			
0.09			

Building Service System Characteristics	
Space Heating Efficiency	78.61%
Domestic Hot Water Efficiency	78.84%
Predominant Primary Heating Source and Generator Type	Traditional centralised oil boiler to serve the space heating and domestic hot water

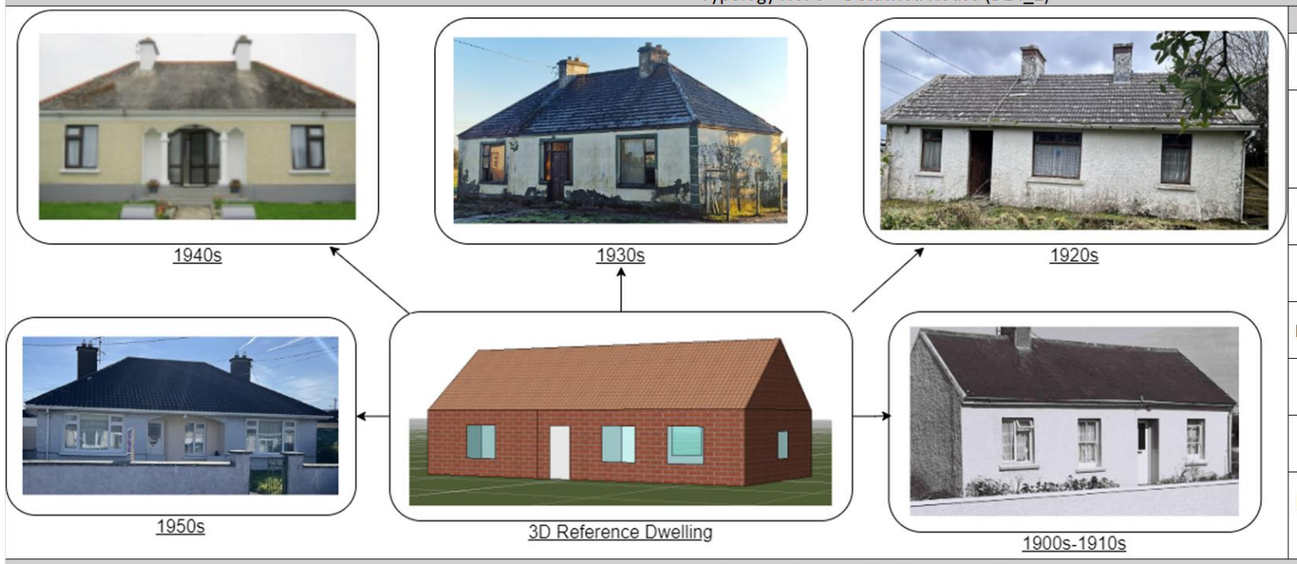
Reference Dwelling Description

Rural traditional detached house with side extension, uninsulated solid brick/concrete external wall rendered externally and with 13mm lime plaster internally and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid external doors. Retrofit required.

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

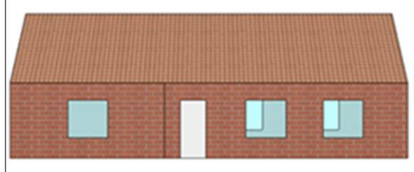
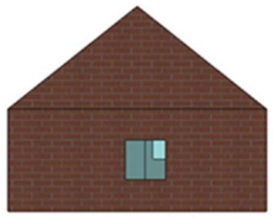
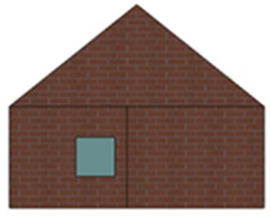
Table 7 Typology No.7 - 1860 to 1976 Detached House with Extension with Oil Boiler

Typology No. 8 – Detached House (DE4_2)



Typology Details	
Typology	Detached House (DE4_2)
Construction Period	Avg. 1936 (Year Range: 1860-1976)
Floor Area (m^2)	90.64
Living Area (%)	20.9%
Representativeness (%)	4.10%
Architectural Style	Single Storey, Sloped Roof, Central Doors
Building Energy Rating Reference	G
Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

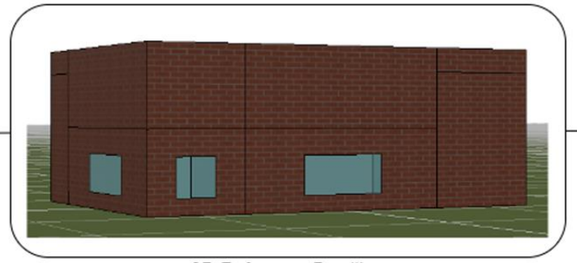
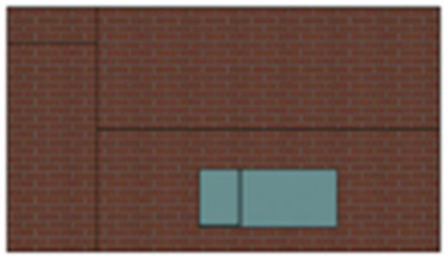
Thermal Characteristics			
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)
External Wall	225mm Solid Brick rendered externally and with 13mm lime plaster internally.	1.75	96.87
Roof	<50 mm mineral wool Insulation between ceiling joists, roof space, tiling.	0.71	90.64
Ground Floor	Solid ground floor, uninsulated	0.78	90.64
Windows	Double glazed windows, uncoated, PVC/Wood frame	3.57	14.66
Doors	Solid external door	2.92	3.26
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)			
16.2			
Thermal Bridging Coefficient (W/m^2K)			
0.09			

Building Service System Characteristics	
Space Heating Efficiency	76.73%
Domestic Hot Water Efficiency	76.98%
Predominant Primary Heating Source and Generator Type	Traditional centralised oil boiler to serve the space heating and domestic hot water

Reference Dwelling Description
Rural traditional detached bungalow, uninsulated solid brick/concrete external wall rendered externally and with 13mm lime plaster internally and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid external doors. Retrofit required.

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

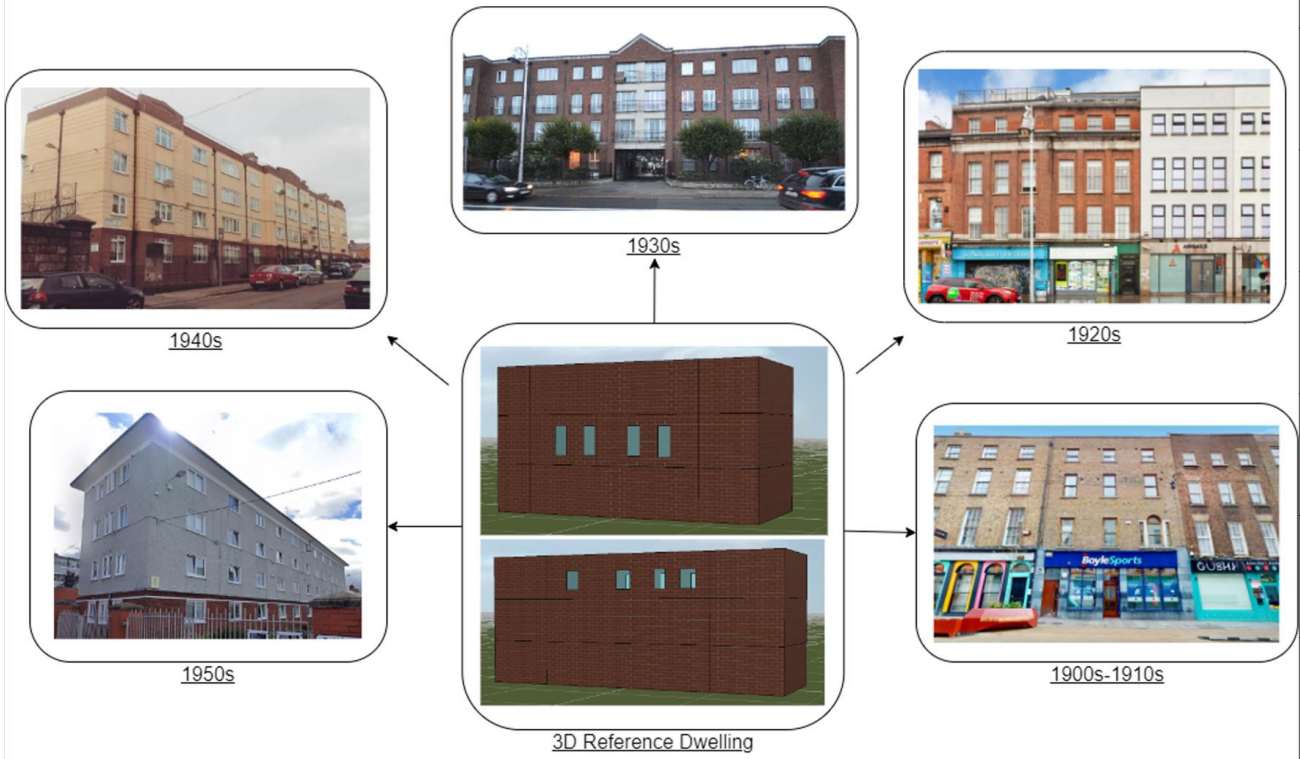
Table 8 Typology No.8 - 1860 to 1976 Detached Bungalow with Oil Boiler

Typology No. 9 – Ground Floor Apartment (GA1)					
 2005-2010  3D Reference Dwelling  2000-2005				Typology Details	
				Typology	Ground Floor Apartment (GA1)
				Construction Period	Avg. 2003 (Year Range: 2002-2006)
				Floor Area (m^2)	67.98
				Living Area (%)	39.0%
				Representativeness (%)	4.00%
				Architectural Style	Single Storey Apartment
				Building Energy Rating Reference	C1
				Requiring Retrofit/New Build	Requiring Retrofit
Elevation Images of Reference Dwelling					
Front		Back		Side 1	Side 2
					
Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	87.91%
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.29	43.31	Domestic Hot Water Efficiency	88.32%
Roof	-	-	-	Predominant Primary Heating Source and Generator Type	Modern centralised natural gas boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, insulated	0.34	67.98	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.39	10.77	Urban modern ground floor apartment, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and insulated ground floor, double-glazed windows and solid semi-exposed doors to common corridor . Retrofit required.	
Doors	Solid external/semi-exposed door	1.96	1.69		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
10.0					
Thermal Bridging Coefficient (W/m^2K)					
0.18					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 9 Typology No.9 - 2002 to 2006 Ground Floor Apartment with Gas Boiler

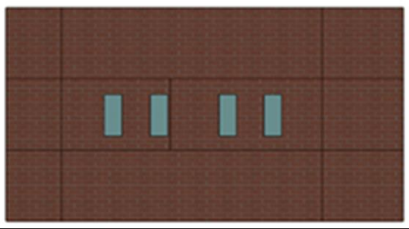
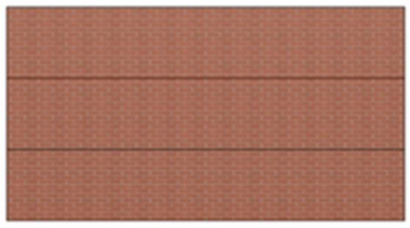
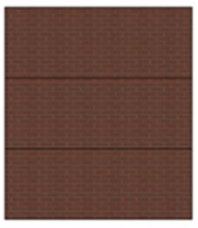
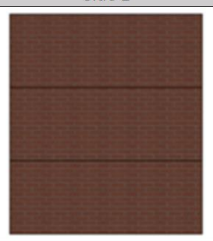
Typology No. 10 and 11 - Mid-Floor Apartment (MA1), Top Floor Apartment (TA1)



Typology Details	
Typology	Mid-Floor Apartment (MA1) and Top Floor Apartment (TA1)
Construction Period	Avg. 1923/1922 (Year Range: 1900-1950/1952)
Floor Area (m^2)	47.02/48.17
Living Area (%)	MA1 – 40.6%, TA1 – 39.2%
Representativeness (%)	MA1 – 3.9%, TA1 – 3.7%
Architectural Style	Single Storey Apartment
Building Energy Rating Reference	MA1 - D2/TA1 - E1
Requiring Retrofit/New Build	Requiring Retrofit

MA1

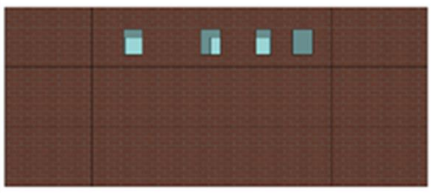
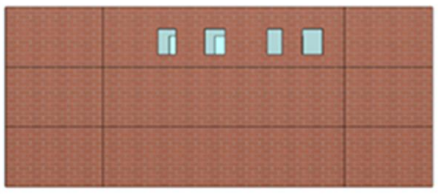
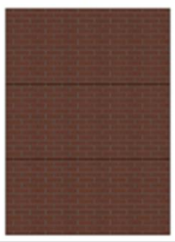
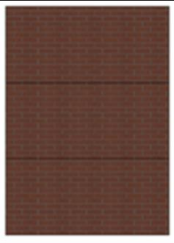
Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	85.57%
External Wall	225mm Solid Brick rendered externally and with 13mm lime plaster internally.	1.55	38.94	Domestic Hot Water Efficiency	86.11%
Roof	-	-	-	Predominant Primary Heating Source and Generator Type	Tradtional centralised natural gas boiler to serve the space heating and domestic hot water
Ground Floor	-	-	-	Reference Dwelling Description	
Windows	Single glazed windows	3.49	7.58	Urban traditional middle floor apartment, uninsulated solid brick/concrete external wall rendered externally and with 13mm lime plaster internally, single-glazed windows and solid semi-exposed doors to common corridor. Retrofit required.	
Doors	Solid external/semi-exposed door	1.77	1.61		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
10.0					
Thermal Bridging Coefficient (W/m^2K)					
0.10					

TA1

Elevation Images of Reference Dwelling

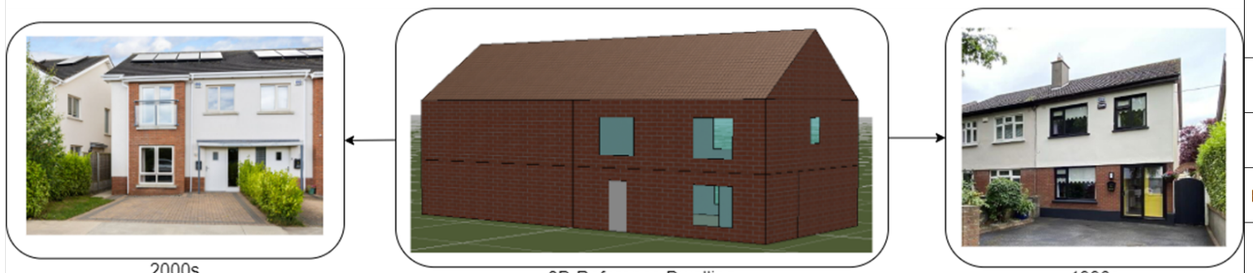
Front	Back	Side 1	Side 2
			

Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	85.16%
External Wall	225mm Solid Brick rendered externally and with 13mm lime plaster internally.	1.55	42.46	Domestic Hot Water Efficiency	85.92%
Roof	Flat roof, uninsulated	0.71	46.87	Predominant Primary Heating Source and Generator Type	Tradtional centralised natural gas boiler to serve the space heating and domestic hot water
Ground Floor	-	-	-	Reference Dwelling Description	
Windows	Single/Double glazed windows, PVC/Wood frame	3.36	6.57	Urban traditional top floor apartment, uninsulated solid brick/concrete external wall rendered externally and with 13mm lime plaster internally with uninsulated flat roof, single-glazed windows and solid semi-exposed doors to common corridor. Retrofit required.	
Doors	Solid external/semi-exposed door	1.7	1.51		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
10.7					
Thermal Bridging Coefficient (W/m^2K)					
0.08					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

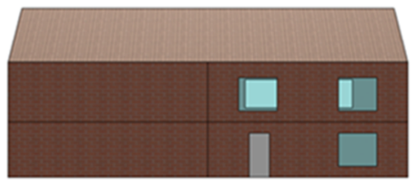
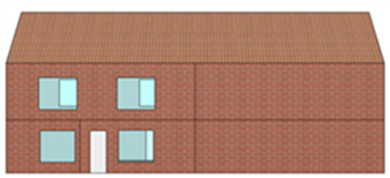
Table 10 Typology No.10&11 - 1900 to 1950/1952 Middle/Top Floor Apartment with Gas Boiler

Typology No. 12 – Semi-Detached House (SD3)



Typology Details	
Typology	Semi-Detached House (SD3)
Construction Period	Avg. 1997 (Year Range: 1997-2005)
Floor Area (m^2)	126.9
Living Area (%)	16.3%
Representativeness (%)	3.60%
Architectural Style	Two Storey, Sloped Roof, Central Doors
Building Energy Rating Reference	C1
Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling

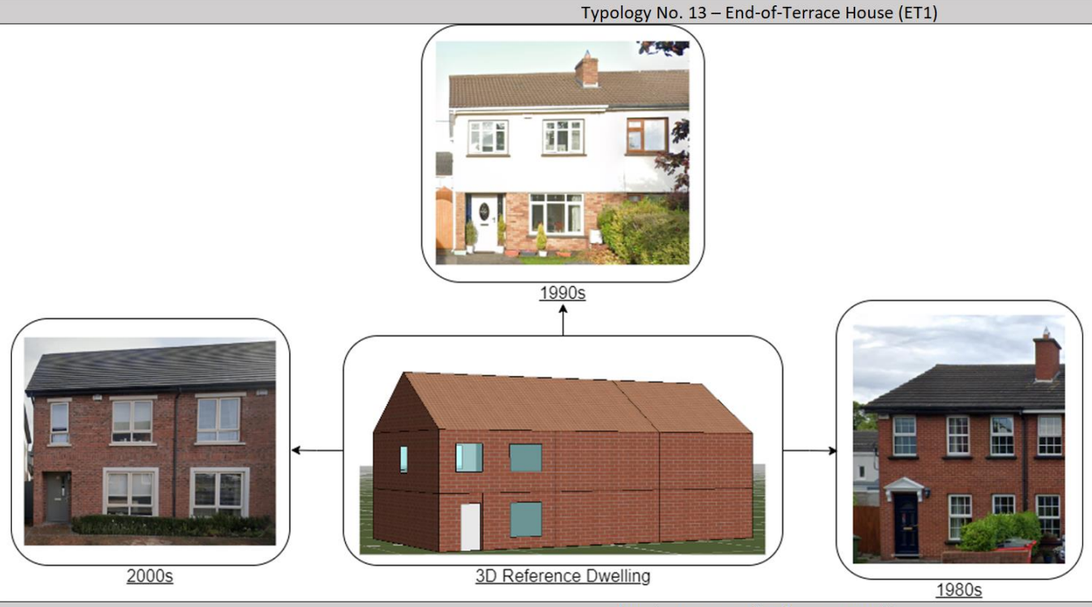
Front	Back	Side 1	Side 2
			

Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	84.15%
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.39	106.63	Domestic Hot Water Efficiency	84.15%
Roof	100 mm mineral wool Insulation between ceiling joists and 50 mm of mineral wood quilt over joists, roof space, tiling.	0.28	68.19	Predominant Primary Heating Source and Generator Type	Modern centralised natural gas boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, insulated	0.40	68.19	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.47	21.46	Suburban/urban modern semi-detached house, typically in modern housing schemes/developments, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid door. Retrofit required.	
Doors	Solid external door	2.80	3.35		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
4.9					
Thermal Bridging Coefficient (W/m^2K)					
0.11					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

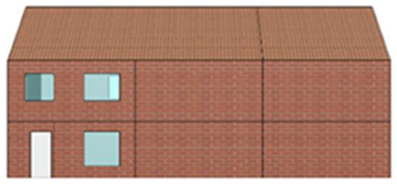
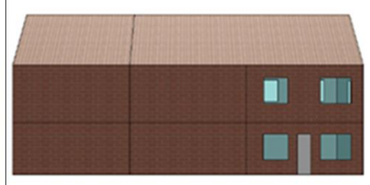
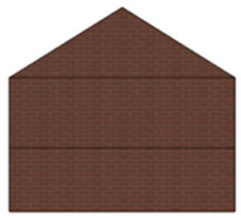
Table 11 Typology No.12 - 1997 to 2005 Semi-Detached House with Gas Boiler

Typology No. 13 – End-of-Terrace House (ET1)



Typology Details	
Typology	End of Terrace (ET1)
Construction Period	Avg. 1989 (Year Range: 1980-2003)
Floor Area (m^2)	83.82
Living Area (%)	20.2%
Representativeness (%)	3.30%
Architectural Style	Two Storey, Sloped Roof
Building Energy Rating Reference	C3
Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

Thermal Characteristics			
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.54	83.10
Roof	100 mm mineral wool Insulation between ceiling joists and 100 mm of mineral wood quilt over joists, roof space, tiling.	0.43	42.67
Ground Floor	Solid ground floor, uninsulated	0.54	42.67
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.62	12.93
Doors	Solid external door	2.89	2.99
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)			
5.5			
Thermal Bridging Coefficient (W/m^2K)			
0.12			

Building Service System Characteristics	
Space Heating Efficiency	81.93%
Domestic Hot Water Efficiency	81.88%
Predominant Primary Heating Source and Generator Type	Modern centralised natural gas boiler to serve the space heating and domestic hot water

Reference Dwelling Description

Suburban/urban modern terrace house, typically in modern housing schemes/developments, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid door. Retrofit required.

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

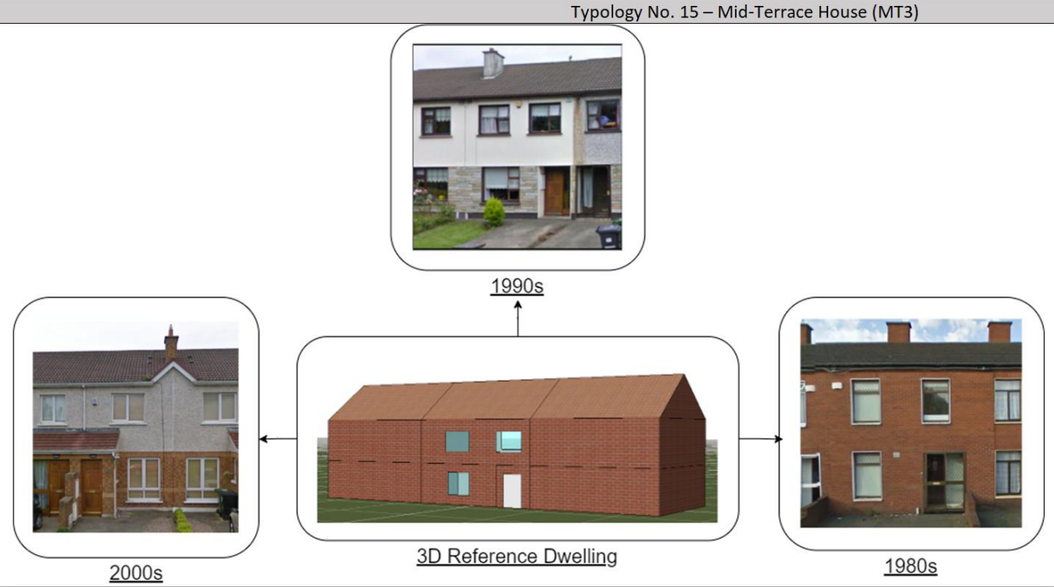
Table 12 Typology No.13 - 1980 to 2003 End-of-Terrace House with Gas Boiler

Typology No. 14 – Mid-Terrace House (MT2)					
				Typology Details	
				Typology	Mid-Terrace House (MT2)
				Construction Period	Avg. 1952 (Year Range: 1925-1992)
				Floor Area (m^2)	71.62
				Living Area (%)	26.9%
				Representativeness (%)	2.80%
				Architectural Style	Single Storey, Sloped Roof, Central Doors
				Building Energy Rating Reference	F
				Requiring Retrofit/New Build	Requiring Retrofit
Elevation Images of Reference Dwelling					
Front	Back	Side 1	Side 2		
					
Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	82.96%
External Wall	300mm Cavity (Uninsulated) mostly rendered with cement/sand or exposed brick and internally light plastered.	1.85	53.39	Domestic Hot Water Efficiency	82.67%
Roof	100 mm mineral wool Insulation between ceiling joists, roof space, tiling.	0.71	71.62	Predominant Primary Heating Source and Generator Type	Traditional centralised natural gas boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, uninsulated	0.49	71.62	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.87	11.18	Urban traditional terrace bungalow, typically in historic housing schemes/developments, uninsulated concrete or cavity wall mostly rendered with cement/sand or exposed brick and internally light plastered, sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid door. Retrofit required.	
Doors	Solid external door	2.70	2.80		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
9.7					
Thermal Bridging Coefficient (W/m^2K)					
0.12					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 13 Typology No.14 - 1925 to 1992 Middle-Terrace House with Gas Boiler

Typology No. 15 – Mid-Terrace House (MT3)



Typology Details	
Typology	Mid-Terrace House (MT3)
Construction Period	Avg. 1988 (Year Range: 1982-2006)
Floor Area (m^2)	113.95
Living Area (%)	19.8%
Representativeness (%)	2.50%
Architectural Style	Two Storey, Sloped Roof
Building Energy Rating Reference	C1
Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

Thermal Characteristics			
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.54	66.66
Roof	100 mm mineral wool Insulation between ceiling joists and 50 mm of mineral wood quilt over joists, roof space, tiling.	0.43	57.64
Ground Floor	Solid ground floor, insulated	0.34	57.64
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.35	17.25
Doors	Solid external door	2.70	2.55
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)			
4.1			
Thermal Bridging Coefficient (W/m^2K)			
0.13			

Building Service System Characteristics	
Space Heating Efficiency	85.39%
Domestic Hot Water Efficiency	85.46%
Predominant Primary Heating Source and Generator Type	Modern centralised natural gas boiler to serve the space heating and domestic hot water

Reference Dwelling Description

Suburban/urban modern terrace house, typically in modern housing schemes/developments, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid door. Retrofit required.

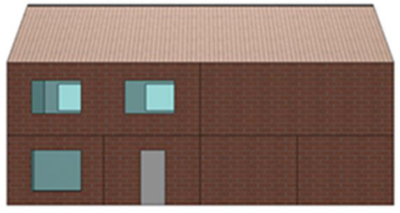
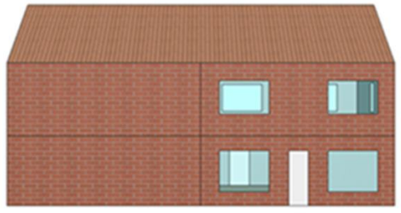
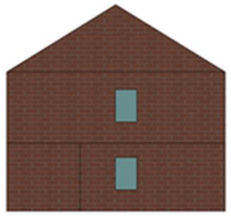
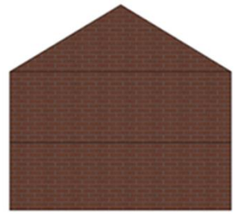
1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 14 Typology No.15 - 1982 to 2006 Middle-Terrace House with Gas Boiler

Typology No. 16 – Semi-Detached House (SD4)

Typology Details	
Typology	Semi-Detached House (SD4)
Construction Period	Avg. 2009 (Year Range: 2003-2019)
Floor Area (m^2)	110.7
Living Area (%)	17.2%
Representativeness (%)	2.00%
Architectural Style	Two Storey, Sloped Roof
Building Energy Rating Reference	B1
Requiring Retrofit/New Build	Retrofitted

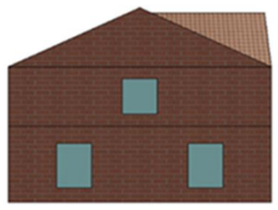
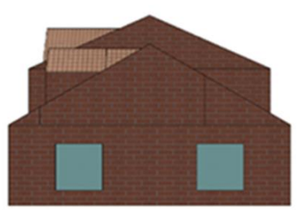
Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	353.13%
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.27	98.11	Domestic Hot Water Efficiency	240.75%
Roof	>100 mm mineral wool Insulation between ceiling joists and >100 mm of mineral wood quilt over joists, roof space, tiling.	0.21	57.36	Predominant Primary Heating Source and Generator Type	Modern centralised air source heat pump to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, insulated	0.26	57.36	Reference Dwelling Description	
Windows	Double glazed windows, coated, PVC frame	1.50	17.40	Suburban/urban modern semi-detached house, typically in modern housing schemes/developments, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows (typically coated and low-e) and solid door. Retrofitted, retrofit not required.	
Doors	Solid external door	1.92	3.22		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
3.0					
Thermal Bridging Coefficient (W/m^2K)					
0.11					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

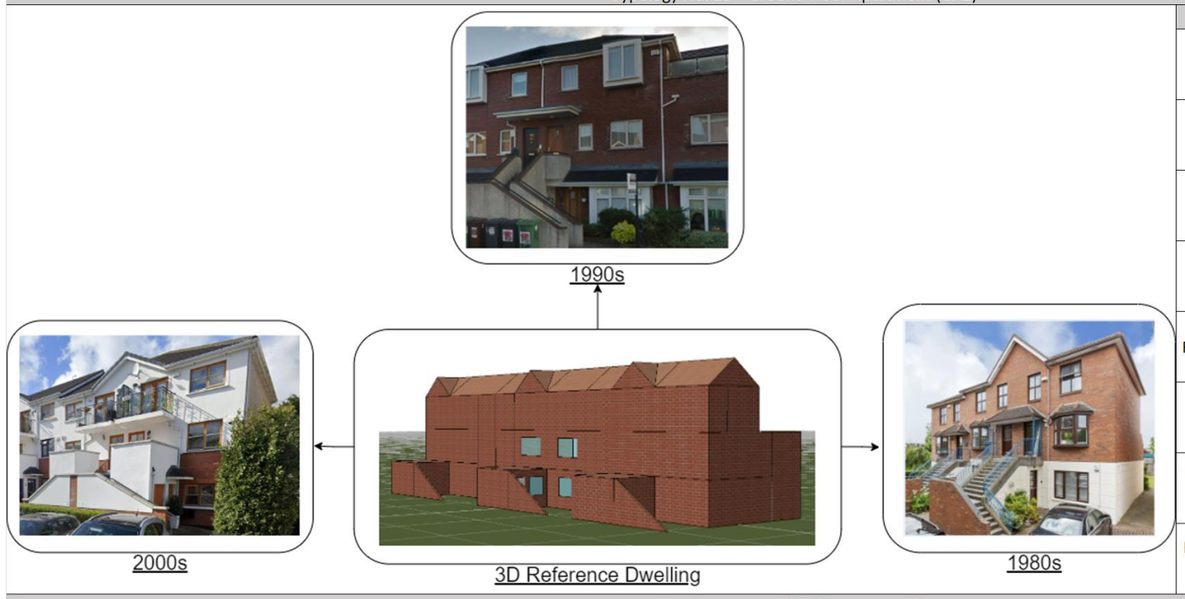
Table 15 Typology No.16 - 2003 to 2019 Semi-Detached House with Air Source Heat Pump

Typology No. 17 – Detached House (DE5)					
				Typology Details	
				Typology	Detached House (DE5)
				Construction Period	Avg. 2009 (Year Range: 1995-2013)
				Floor Area (m^2)	210.79
				Living Area (%)	16.9%
				Representativeness (%)	2.00%
				Architectural Style	Two Storey, Dormer, Extension, Sloped Roof, Central Doors
				Building Energy Rating Reference	B1
				Requiring Retrofit/New Build	Retrofitted
Elevation Images of Reference Dwelling					
Front	Back	Side 1	Side 2		
					
Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	313.70%
External Wall	300mm Cavity (Insulated) with 40-50 mm EPS/XPS insulation board.	0.27	182.20	Domestic Hot Water Efficiency	218.29%
Roof	100 mm mineral wool Insulation between ceiling joists and 100 mm of mineral wood quilt over joists, roof space, tiling.	0.21	141.53	Predominant Primary Heating Source and Generator Type	Modern centralised air source heat pump to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, insulated	0.31	133.30	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	1.84	38.60	Rural/suburban modern detached house with dormers and side extension, insulated cavity external wall with 40-50 mm EPS/XPS insulation board and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows and solid external doors. Retrofitted, retrofit not required.	
Doors	Solid external door	2.34	3.65		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
7.4					
Thermal Bridging Coefficient (W/m^2K)					
0.09					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

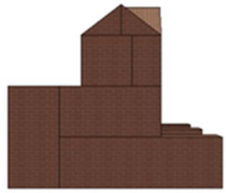
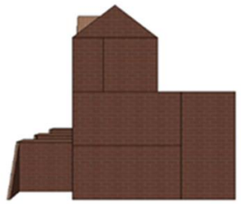
Table 16 Typology No.17 - 1995 to 2013 Detached House with Air Source Heat Pump

Typology No. 18 – Ground Floor Apartment (GA2)



Typology Details	
Typology	Two Storey Apartment/Duplex (GA2)
Construction Period	Avg. 1987 (Year Range: 1985-2005)
Floor Area (m^2)	90.16
Living Area (%)	25.1%
Representativeness (%)	1.60%
Architectural Style	Two Storey,
Building Energy Rating Reference	C3
Requiring Retrofit/New Build	Requiring Retrofit

Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

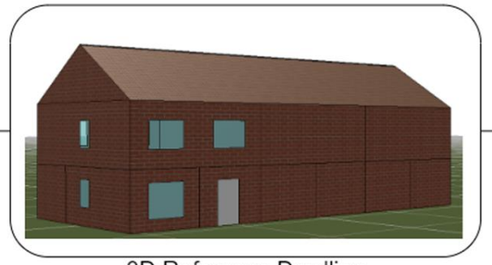
Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	83.14%
External Wall	300mm Cavity (Uninsulated) mostly rendered with cement/sand or exposed brick and internally light plastered.	1.35	66.93	Domestic Hot Water Efficiency	83.14%
Roof	Flat roof, insulated	0.43	32.44	Predominant Primary Heating Source and Generator Type	Modern centralised natural gas boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, insulated	0.45	50.72	Reference Dwelling Description	
Windows	Double glazed windows, uncoated, PVC/Wood frame	2.63	14.88	Suburban/urban modern duplex apartment, typically in modern housing schemes/developments, uninsulated cavity external wall mostly rendered with cement/sand or exposed brick and internally light plastered and insulated flat roof, double-glazed windows and solid door. Retrofit required.	
Doors	Solid external door	2.48	2.31		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
8.6					
Thermal Bridging Coefficient (W/m^2K)					
0.16					

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 17 Typology No.18 - 1985 to 2005 Ground Floor Duplex with Gas Boiler

Typology No. 19 – End-of-Terrace House (ET2)

2010s

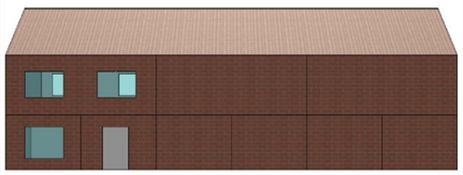
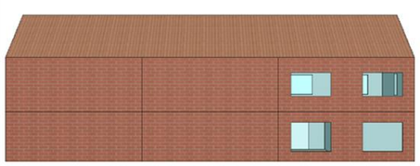
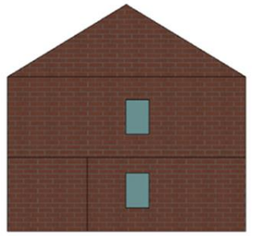


3D Reference Dwelling

2020s

Typology Details	
Typology	End-of-Terrace House (ET2)
Construction Period	Avg. 2016 (Year Range: 2007-2020)
Floor Area (m^2)	108.99
Living Area (%)	18.1%
Representativeness (%)	1.50%
Architectural Style	Two Storey, Sloped Roof
Building Energy Rating Reference	A3
Requiring Retrofit/New Build	New Build

Elevation Images of Reference Dwelling

Front	Back	Side 1	Side 2
			

Thermal Characteristics			
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)
External Wall	Timber Frame with external finishes such as exposed masonry, lightweight cladding, wooden panels, render on lathe.	0.27	98.67
Roof	>100 mm mineral wool Insulation between ceiling joists and >100 mm of mineral wood quilt over joists, roof space, tiling.	0.21	55.25
Ground Floor	Solid ground floor, insulated	0.16	55.25
Windows	Double glazed windows, coated, PVC frame	1.31	19.24
Doors	Solid external door	1.51	2.44
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)			
3.0			
Thermal Bridging Coefficient (W/m^2K)			
0.11			

Building Service System Characteristics	
Space Heating Efficiency	90.23%
Domestic Hot Water Efficiency	91.21%
Predominant Primary Heating Source and Generator Type	Modern centralised natural gas boiler to serve the space heating and domestic hot water
Reference Dwelling Description	
Suburban/urban modern terrace house, typically in modern housing schemes/developments, insulated timer frame external wall with external finishes such as exposed masonry, lightweight cladding, wooden panels, render on lathe and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows (typically coated and low-e) and solid door. New build, retrofit not required.	

1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022

Table 18 Typology No.19 - 2007 to 2020 End-of-Terrace House with Gas Boiler

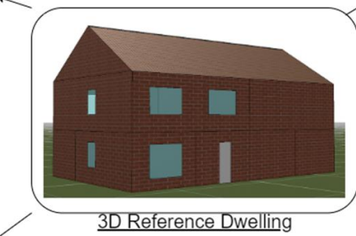
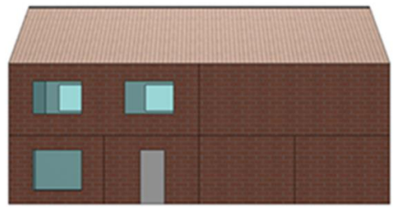
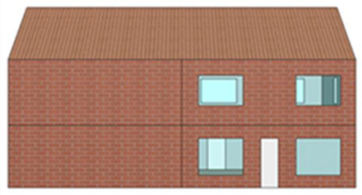
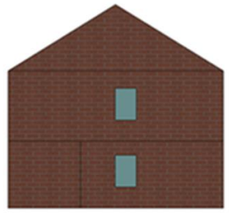
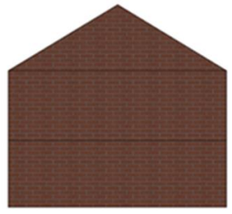
Typology No. 20 – Semi-Detached House (SD5)					
 1990s  2000s  3D Reference Dwelling  2010s  2020s				Typology Details	
				Typology	Semi-Detached House (SD5)
				Construction Period	Avg. 2013 (Year Range: 1993-2019)
				Floor Area (m^2)	118.35
				Living Area (%)	16.1%
				Representativeness (%)	1.50%
				Architectural Style	Two Storey, Sloped Roof
				Building Energy Rating Reference	A3
				Requiring Retrofit/New Build	New Build
Elevation Images of Reference Dwelling					
Front		Back		Side 1	Side 2
					
Thermal Characteristics				Building Service System Characteristics	
Building Elements	Predominant Build Ups[1]	U-value (W/m^2K)	Element Area (m^2)	Space Heating Efficiency	89.58%
External Wall	Timber Frame with external finishes such as exposed masonry, lightweight cladding, wooden panels, render on lathe.	0.27	102.04	Domestic Hot Water Efficiency	89.50%
Roof	>100 mm mineral wool Insulation between ceiling joists and >100 mm of mineral wood quilt over joists, roof space, tiling.	0.21	60.48	Predominant Primary Heating Source and Generator Type	Modern centralised natural gas boiler to serve the space heating and domestic hot water
Ground Floor	Solid ground floor, insulated	0.19	60.48	Reference Dwelling Description	
Windows	Double glazed windows, coated, PVC/Wood frame	1.48	20.34	Suburban/urban modern semi-detached house, typically in modern housing schemes/developments, insulated timer frame external wall with external finishes such as exposed masonry, lightweight cladding, wooden panels, render on lathe and sloped roof with insulation at ceiling level (typically mineral wool), double-glazed windows (typically coated and low-e) and solid door. New build, retrofit not required.	
Doors	Solid external door	1.80	2.75		
Air Permeability ($m^3.h^{-1}/m^2$ @ 50Pa)					
3.0					
Thermal Bridging Coefficient (W/m^2K)					
0.11					
1. Build ups of the construction are determined based on Raushan et al. (2022)'s research: Determining realistic U-values to substitute default U-values, Energy & Buildings, 274-112358, 2022					

Table 19 Typology No.20 - 1993 to 2019 Semi-Detached House with Gas Boiler

Acknowledgements

This research was part supported by MaREI, the SFI Research Centre for Energy, Climate and Marine [Grant No: 12/RC/2303-P2] and the Sustainable Energy Authority of Ireland's (SEAI) National Energy Research Development and Demonstration (RD&D) Fund [RDD/855].

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